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Increasing the level of operational detail in LT energy-system planning models

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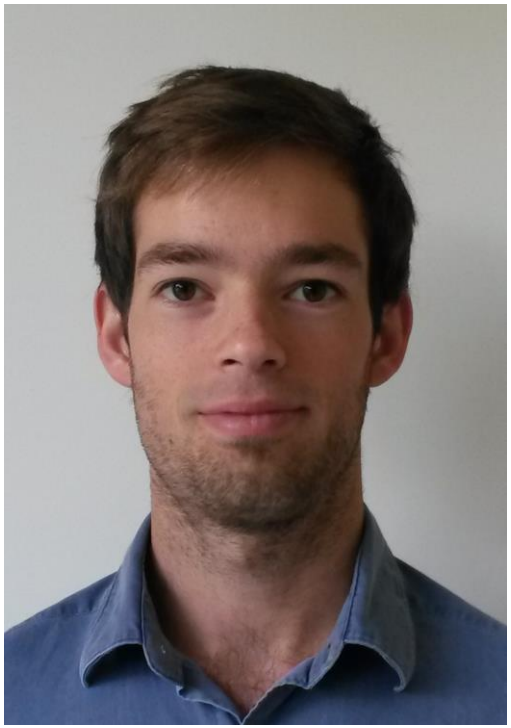
Who am I?



- PhD Researcher @ KU Leuven/VITO
- Supervisors: Dr. Erik Delarue, Prof. Dr. William D'haeseleer
- 'Long-term optimization of electricity systems – addressing flexibility and market design issues'

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Who are we?

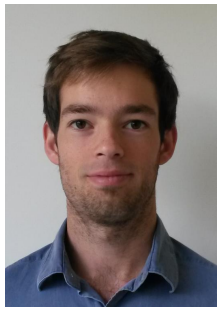
- The electricity generation systems modeling group
  - Part of Mechanical Engineering department
  - Main focus on the development and application of electricity generation models
  - Involved in several research projects (e.g., E-highways)
  - Teaching master courses on energy systems

Prof. Dr. William D'haeseleer

Dr. Erik Delarue

Kenneth Bruninx

Kenneth Van den Bergh



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Andreas Belderbos

What do we do? Model development & applications

- Operational models (Unit commitment)
  - Model formulation for large-scale problems
    - Mixed-integer programming
      - Tightness
      - Compactness
    - Heuristic approach
  - Integration of intermittent renewables
    - unpredictability: stochastic models
    - Variability: flexibility options
  - New technologies
    - P2G, CCS, active grid elements
- **Expansion planning models**
  - **TIMES framework**
  - **Operational aspects**
    - **Temporal**
    - **Techno-economic**
  - **Portfolio theory approach**
- Impact of energy policies
  - Renewables deployment
  - Nuclear phase out
- Impact of EU Emission Trading System
  - Coal-to-gas fuel switching
  - Marginal abatement cost curve for power sector
- Interacting policies
  - Renewable targets and EU ETS

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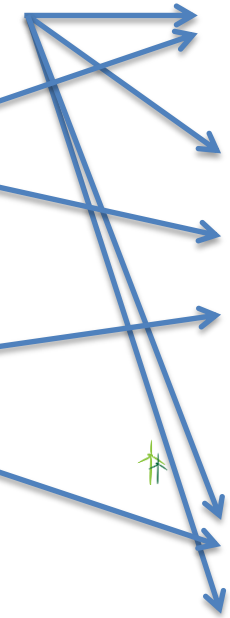
Content

- Context – Problem statement
- Impact of the operational detail in LT planning models
- Increasing the level of operational detail in LT planning models
- Future work & conclusions

Context

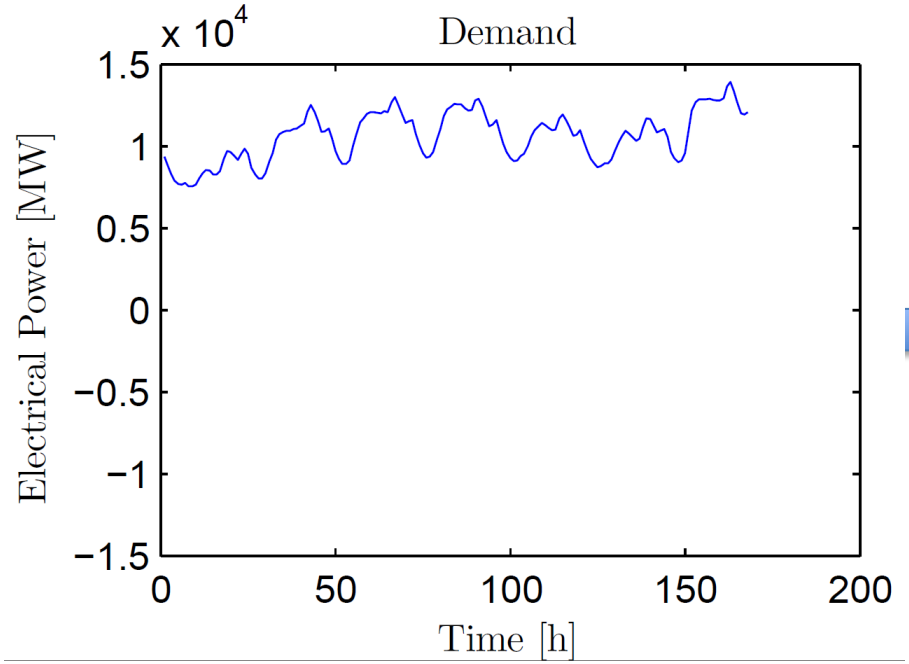
- Intermittent Renewables:
  - Variable generation
  - Limited predictability (forecast errors)
  - Location specific
  - Capital intensive (low OPEX, high CAPEX)



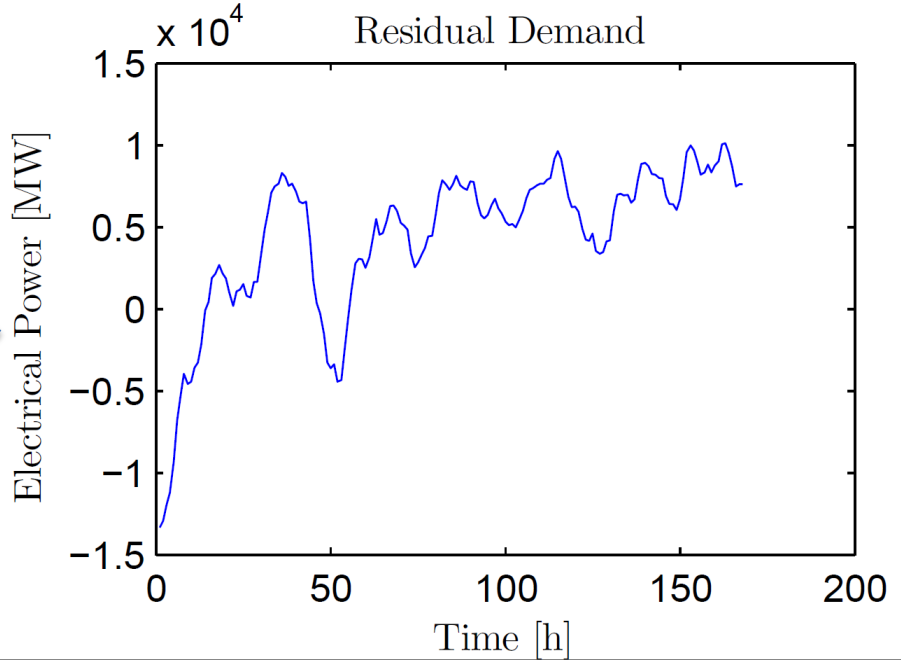
- Impact on the power system:
  - Technical (Supply = Demand)
    - Limited load-following capabilities dispatchable power plants
    - Need for sufficient back-up capacity
    - Increased need for operating reserves
    - Increased need for transmission capacity
  - Economic (Profitability)
    - Lower, more volatile electricity prices
    - Reduced number of operating hours

1) Context

Peak demand: 14GW



Peak demand: 14GW
Wind turbines: 24GW

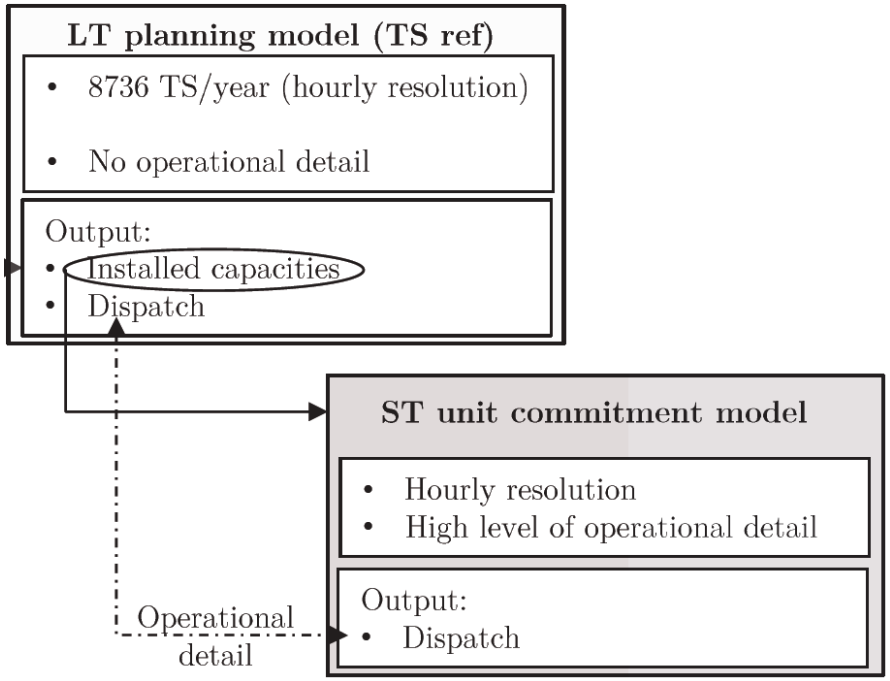


Problem statement

- Computationally Demanding:
  - Technology rich
  - Large geographical area
  - Long time horizon
- => Model simplifications:
  - Temporal representation:
    - Limited number of time slices (1-12)
    - Deterministic (Short-term)
  - Spatial representation:
    - Nationally aggregated regions
  - Operational representation:
    - Technology-type level (no single units)
    - Limited techno-economic operational detail (E.g. Ramping rates, start-up costs)

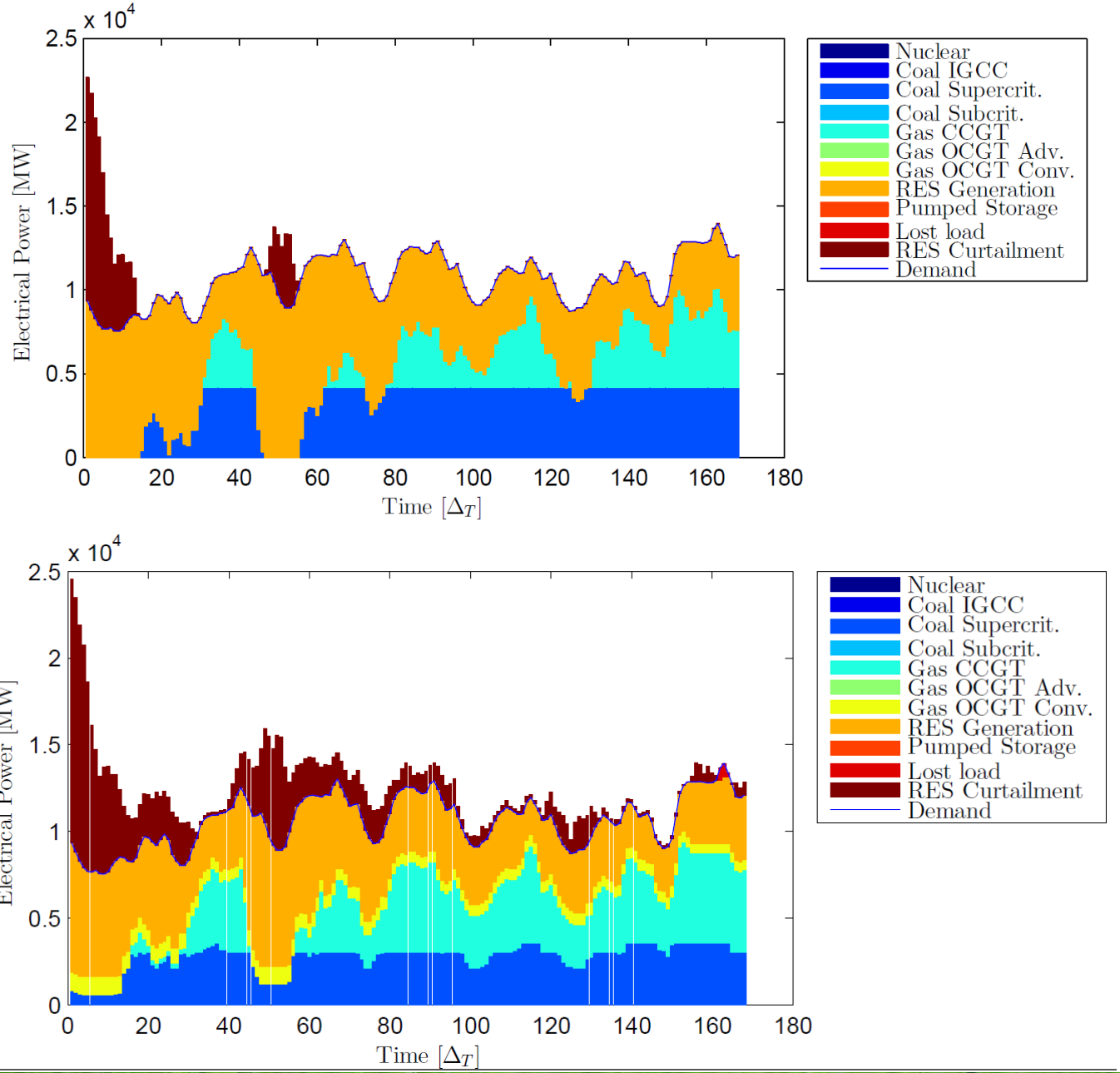
Impact of the level of operational detail

- **Research Question**: What is the impact of the limited techno-economic operational detail in planning models?
  - Operational detail => Dispatch =>
    - Generation Shares
    - Primary Fuel Consumption
    - Operational costs
    - Security of Supply
- **Methodology**:



- Island Operation (no cross-border trade)
- No grids (single node)
- No operating reserve requirements
- Imposed target share of VRES (TIMES)

The techno-economic operational detail matters



The techno-economic operational detail matters

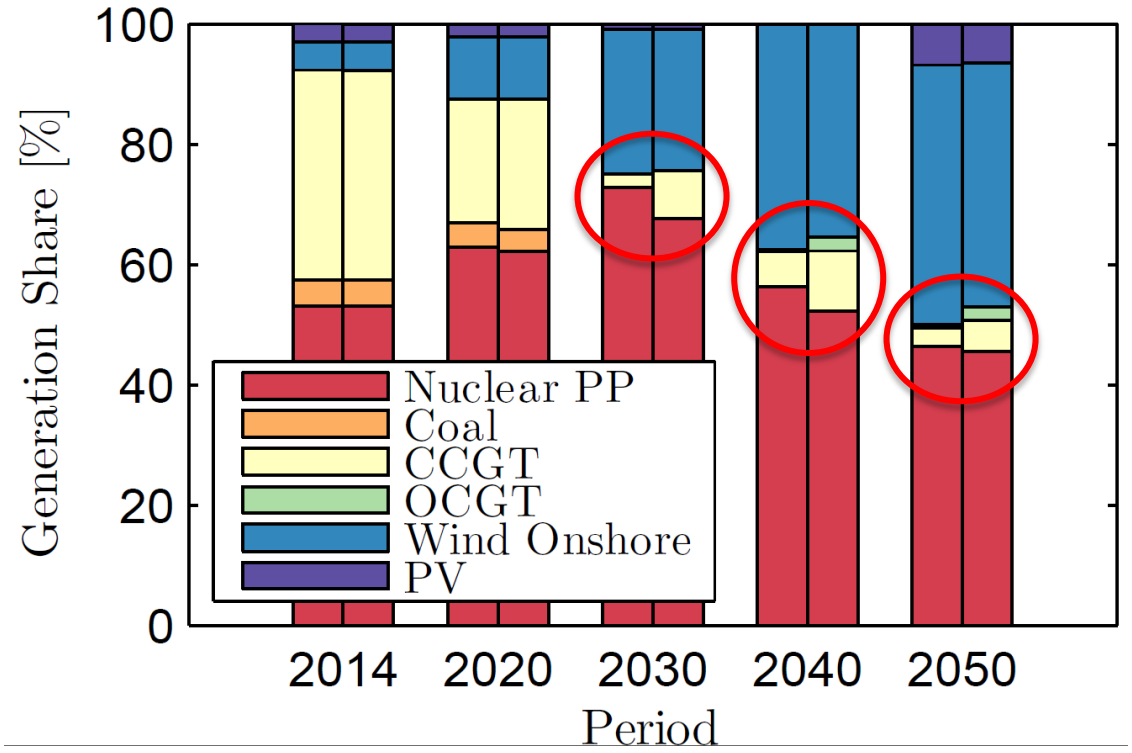
Generation mix:

Overestimation uptake of VRES

	TS ref				
	2014	2020	2030	2040	2050
Excess energy	0	0	0.1	5.6	10.9
Curtailment TIMES	0	0	0	4.3	9.3
Curtailment UC	0	0	2.3	10.7	16.1
Share VRES TIMES	7.8	12.5	25	37.5	50
Share VRES UC	7.8	12.5	24.4	35.5	47.1

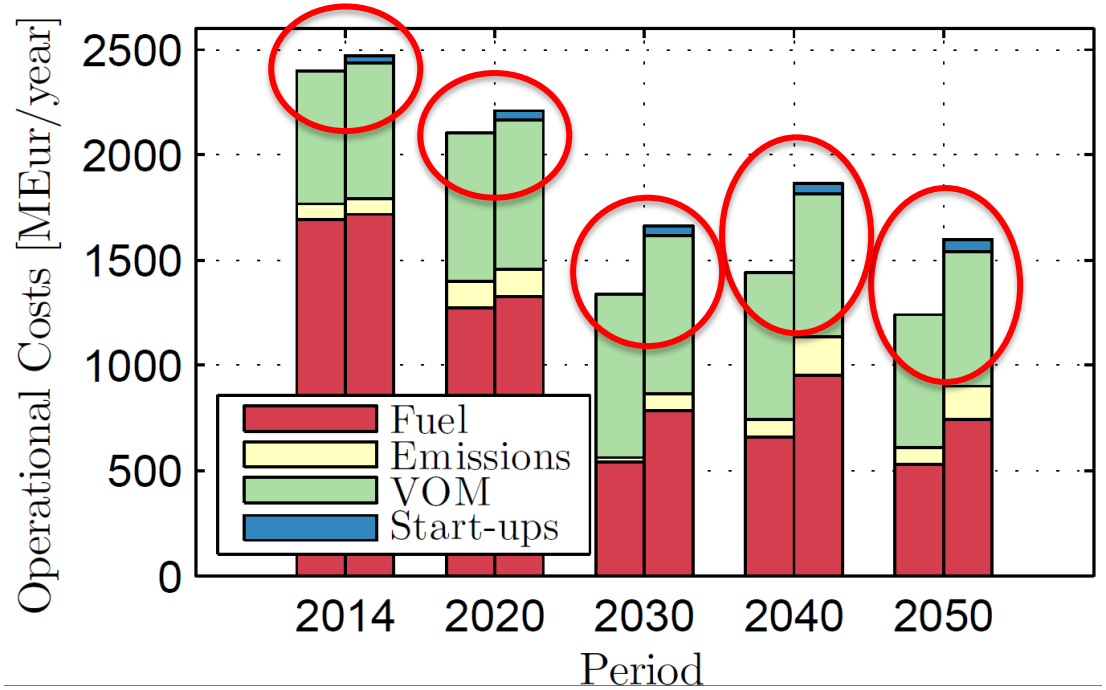
The techno-economic operational detail matters

- Generation mix:
  - Overestimation uptake of VRES
  - **Overestimation inflexible baseload generation**
  - **Underestimation flexible plants**



The techno-economic operational detail matters

- Generation mix:
  - Overestimation uptake of VRES
  - Overestimation inflexible baseload generation
  - Underestimation flexible plants
- **Underestimation Operational cost**



The techno-economic operational detail matters

- Generation mix:
  - Overestimation uptake of VRES
  - Overestimation inflexible baseload generation
  - Underestimation flexible plants
- Underestimation Operational cost
- Security of supply
  - Dependent on peaking equation

⇒ Inaccurate projections of primary fuel consumption, GHG emissions and operational costs

⇒ Sub-optimal investments

⇒ Importance increases with share of VRES

Increasing the techno-economic detail

- Detailed UC & ED
  - Chronological data (load, VRES) @ hourly (or smaller) time step
  - Integer variable to track commitment status (per plant, per time step)
  - => Computationally demanding
- Flexibility constraints for system planning
  - 2 approaches:
    - Direct Integration
    - Soft-link planning model to operational model

Increasing the techno-economic detail

Direct Integration

+

- Single Model

−

- Requires chronological data
- Computational Cost ↗ => highly stylized representation of operating constraints

Soft-link

+

- Computational cost

−

- Manage planning and operational model
- Feedback-loop?
- Convergence?

Direct Integration of operational constraints

- Often highly stylized
  - 'technological ramp rates' representing all dynamic constraints
  - 'Flexibility constraint':
    - assigning a positive flexibility parameter to technologies that can provide flexibility, negative flexibility to VRES, load
    - Overall flexibility >= 0
  - Aim to mimic impact of detailed operational constraints
  - => Do not directly reflect system needs or technological constraints

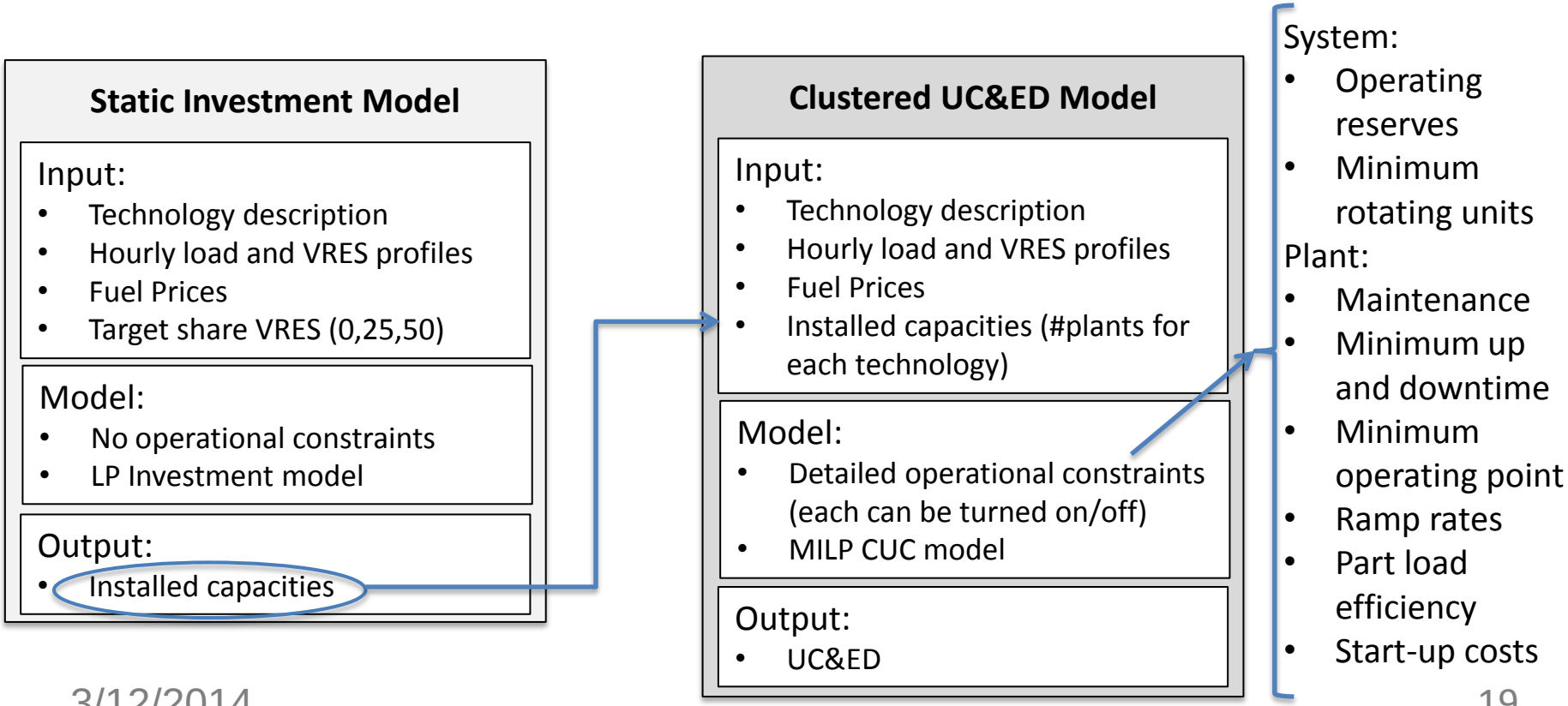
- Validation issues
  - Validation often lacking
  - Extrapolating calibration to historical (low VRES) to future (high VRES)
  - Method generally applicable? System-dependent calibration?

Direct Integration of operational constraints

- Objective: Determine a computationally efficient, validated set of operational constraints that reflect system needs and technological flexibility constraints and associated costs
- Research questions:
  - Which constraints impact results most?
  - Which constraints can be omitted?
  - Interaction between different constraints?
  - What is the impact of relaxing integer variables?
  - Can we identify simplified formulations of critical constraints?

Methodology

- Assess impact of different constraints and of relaxing integer variables on the dispatch for a varying share of RES



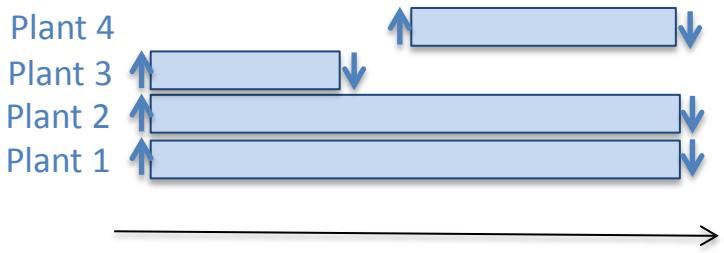
Methodology

- Turn different constraints on/off
- Compare to the reference case = MILP Clustered UC with all constraints
- Metrics for evaluation:
  - Relative Operational cost error
  - Generation Mix error
    - $Gen\ mix\ error = \sum_i \left| share_i - share_i^{ref} \right|$
  - Relative curtailment error
  - (Relative) load shedding error

Intermezzo: Clustered Unit Commitment (CUC)

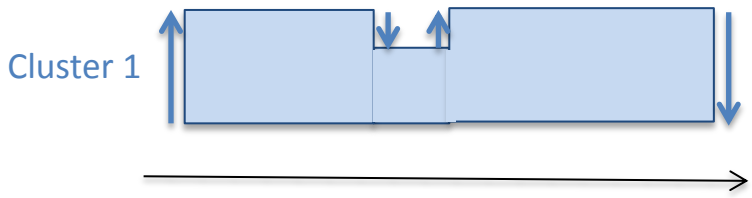
General MILP UC

- Each individual unit
- Commitment status: 1 binary variable (on/off) per plant, per time step



Clustered MILP UC

- Groups similar plants into clusters
  - Here: grouping based on technology
  - Lose plant-specific information (all plants within one cluster are identical)
- Commitment status: 1 integer variable per cluster, per time step
  - Reduction of #variables
  - Reduction of the state space
  - => Reduction of computational cost



Results

- Which constraints matter?
- Which don't?

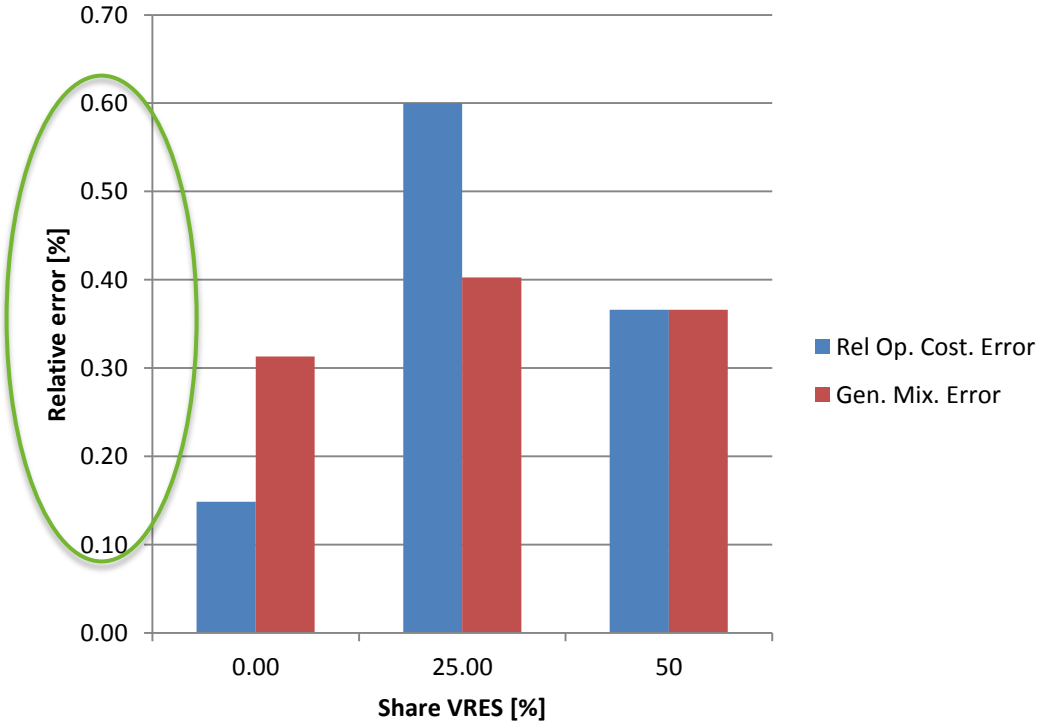
Chronological data necessary?

Results

- Impact reserve requirements strongly dependent on assumptions:
  - Ramp rates, minimum operating point
  - Reserve sizing, market design
- Dependency on system?
  - Ratio dispatchable capacity/Peak demand
  - Amount of baseload generating units
- Linkage between different constraints need to be investigated
  - E.g., Part-load efficiency ⇔ Reserves

Results

- What is the impact of relaxing integer (commitment) variables?



Speed-up: 11-50
But: Strongly dependent on set-up

Future Work

- In depth analysis:
  - Operating reserves
  - Modeling of maintenance
- Interaction different constraints
- Sensitivities to technical parameters
- Integrate relaxed clustered UC in LT planning model/TIMES

Conclusions

- Operational detail matters:
  - Over-estimation uptake RES, over-estimation inflexible baseload, underestimation flexible technologies
  - Sincere underestimation operational cost
  - [illegible] requirements and [illegible] can not be [illegible] seems to be limited
- Some constraints are more important than others
- Relaxing integer variables has limited effect on results, large impact on computational cost

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Questions?

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